Elemental Carbon Emissions from Mobile Sources: Understanding the Controlling Variables and Resulting Vehicle Fleet Averages

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Critical Questions

- What are the primary variables impacting the emissions rates of EC from Spark Ignition (SI) and Compression Ignition (CI) vehicles
- How can representative emissions profiles and emissions factors be estimated for mobile source activities in different urban areas
- In the absence of other major EC sources, what are relative contributions of CI and SI vehicles to EC emissions
- What is the relative contribution of SI and CI vehicles to EC emissions in the presences of other important EC sources
- Are the answers to the above questions different for different definitions of EC and BC

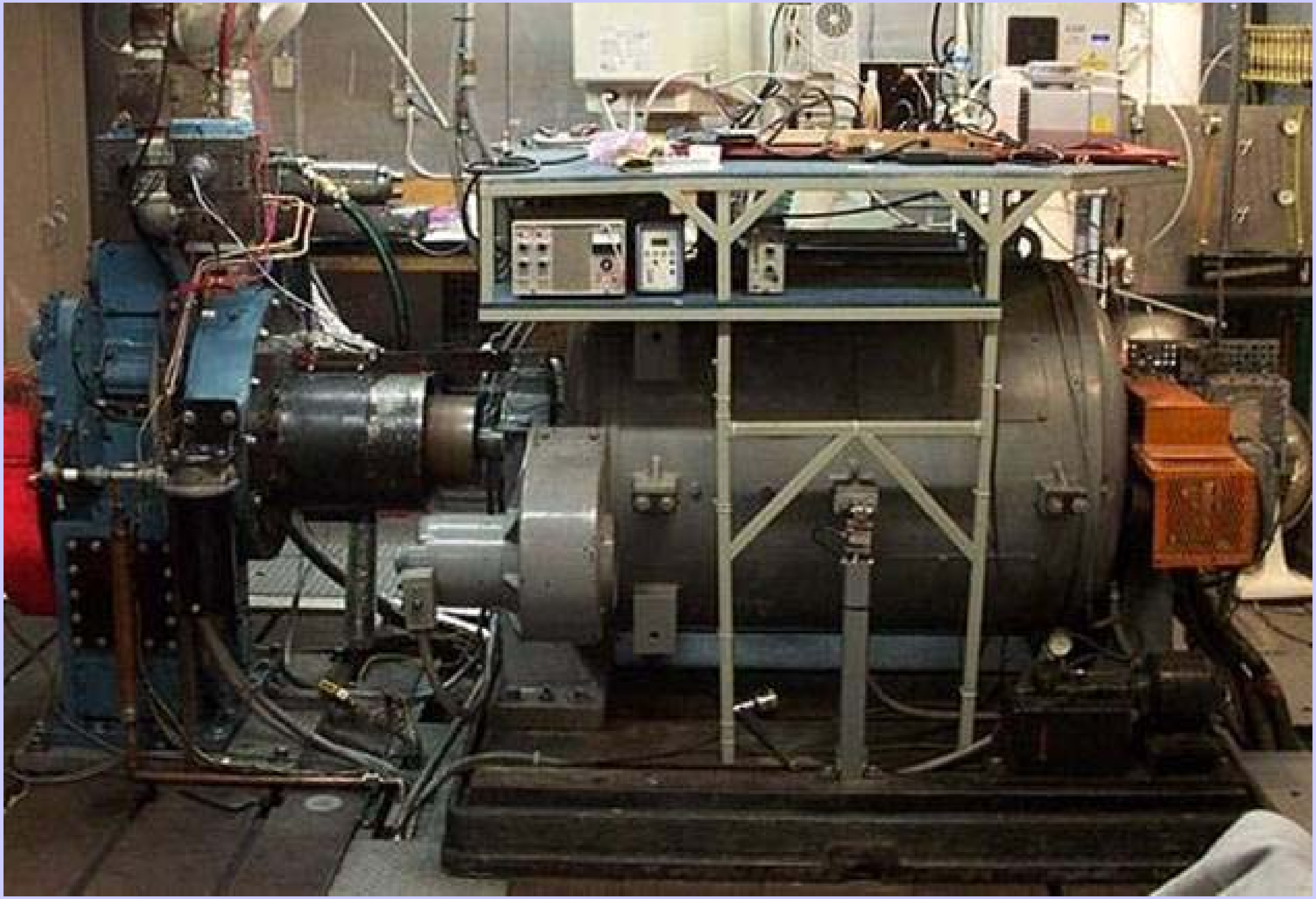
Cautionary Notes

- All of the measurements that I will discuss are based on NIOSH 5040 using the ACE-Asia protocol (Schauer et al., 2003)
  - Defined as Elemental Carbon (EC)
- I will not present any absorption measurements
  - Defined as Black Carbon (BC)
- There are strong correlations between BC, NIOSH EC and IMPROVE EC
  - The relationships among these different parameters vary with EC sources

What impacts EC emissions

- Driving Cycle
- Cold Start Conditions
- Fuel Composition
- Vehicle Distribution
  - Engine Technology
  - Engine Maintenance
  - Exhaust after treatment

Diesel Engine Research Lab



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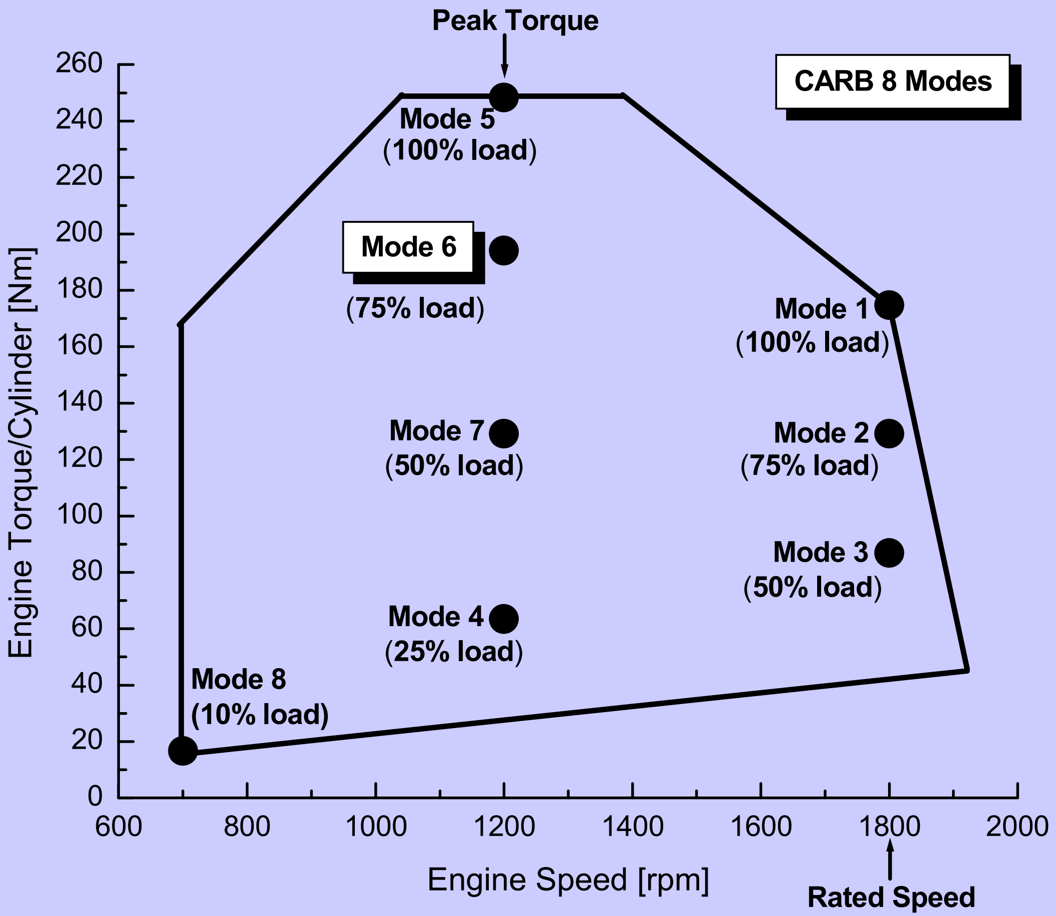
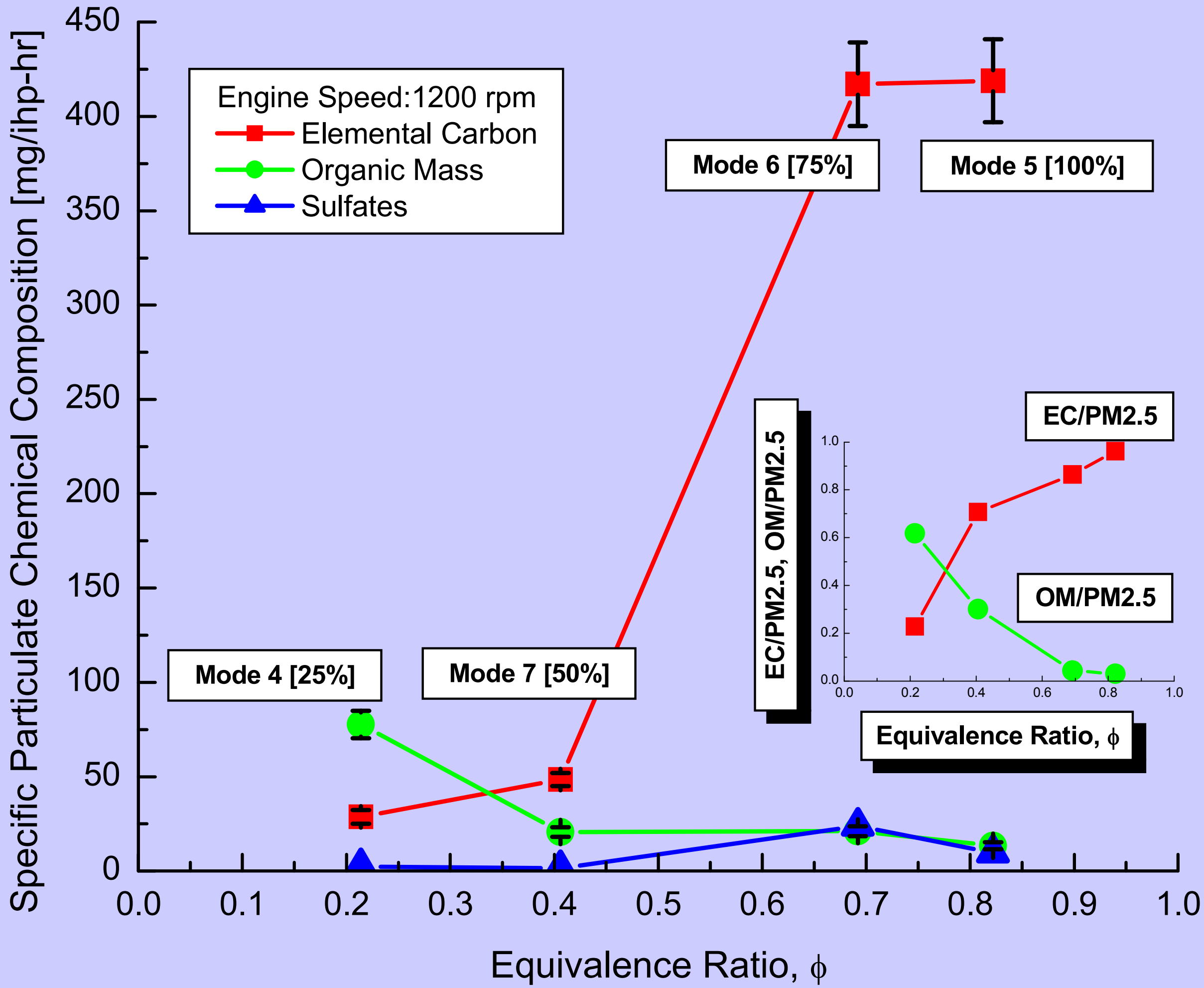
CARB 8 Mode Cycle – Diesel Engine



Effect of Engine Load – Diesel Engine (Kweon et al., 2002, SAE 2002-01-2670)



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Effect of Fuel – Diesel Engine

(Kweon et al., 2002, SAE 2003-01-1899)

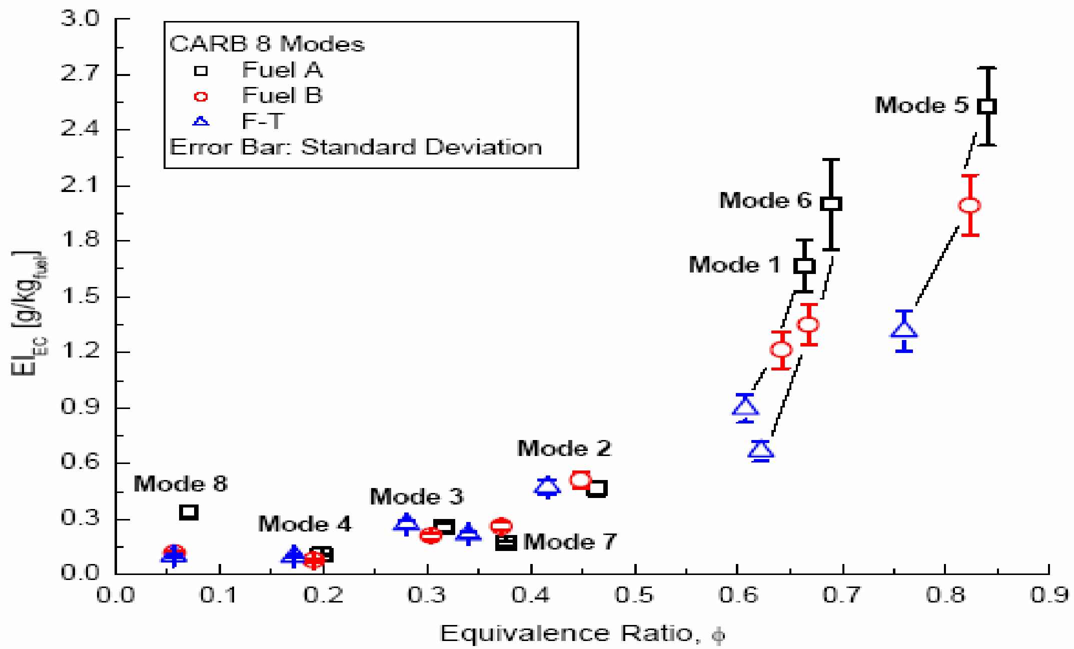


Figure 18. Emission index (EI) of EC vs. equivalence ratio (ϕ) for Fuel A, Fuel B, and F-T fuel for CARB 8-mode test cycle.

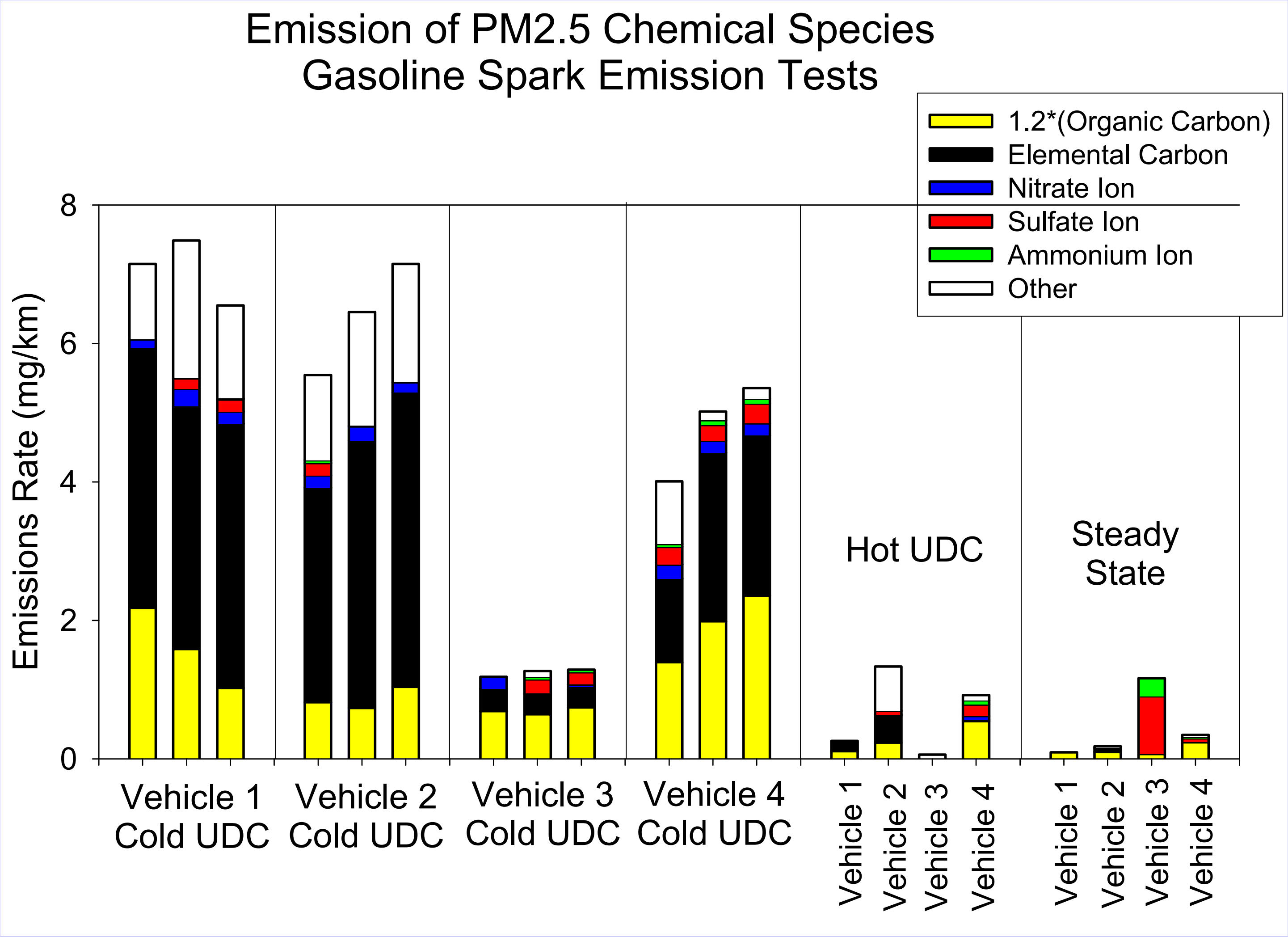
Effect of Cold-Cold Start - Gasoline

DOE/NREL Cold-Cold Start Study

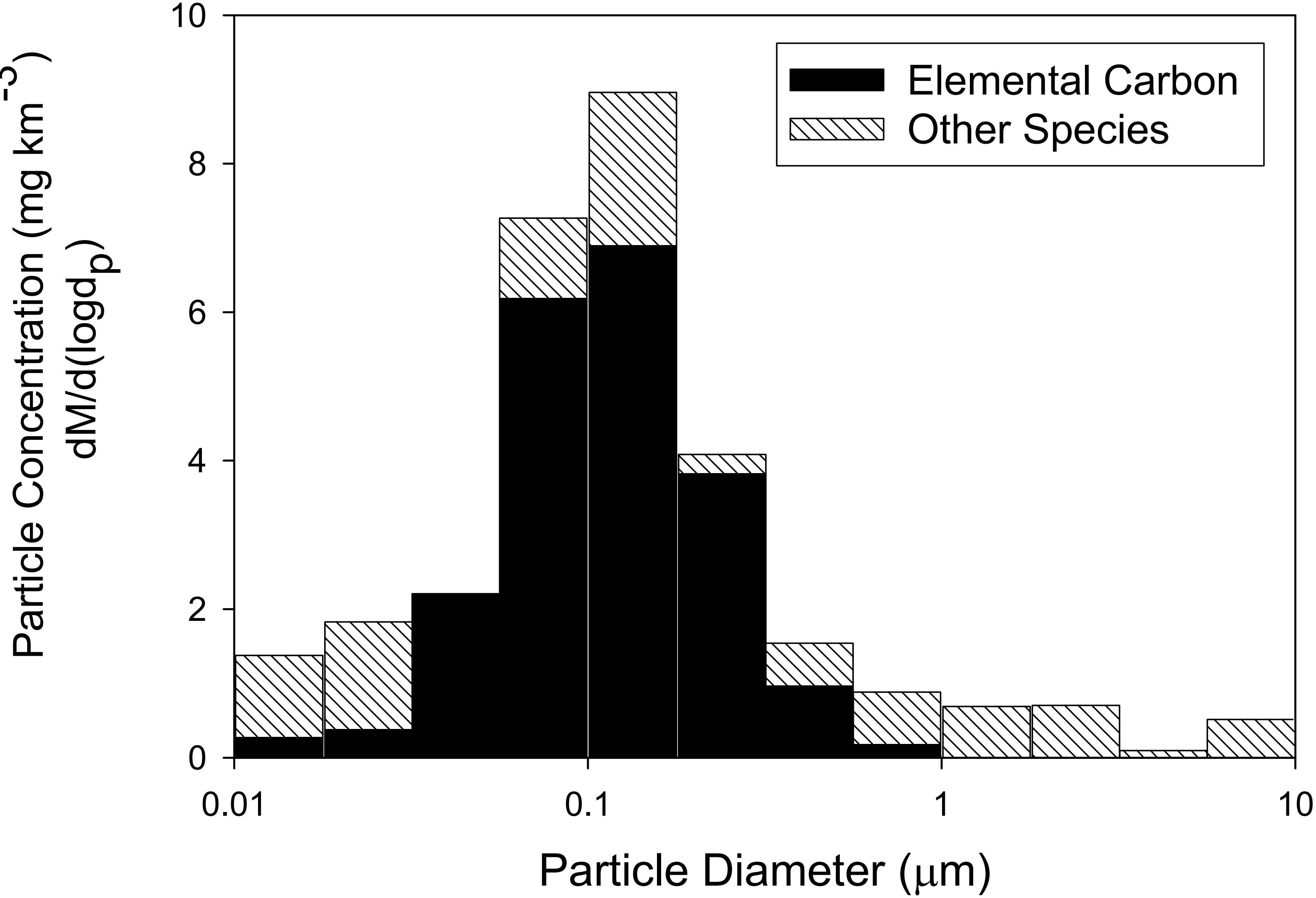
Schauer et al., 2003 – DOE Report

- Four on-road vehicles
  - 1999 Ford F150
  - 1998 Ford Windstar
  - 1995 Ford Escort
  - 1999 Chevy Prism
- Each Vehicle Tested
  - 3 “Cold-Cold” UDC – Engine Oil at 0 ^{o}C
  - 3 Hot UDC – Composited to One Sample per Vehicle
  - Steady State Driving – 20, 35, 65, and 70 MPH
- Five Dilution Tunnel Blanks
- Daily Dilution Air Blanks

Cold-Cold Start Gasoline Engine EC Emissions



Particle Size Distribution for Cold-Cold Start UDC Driving Cycle
Test 13 - Vehicle 2 -Windstar

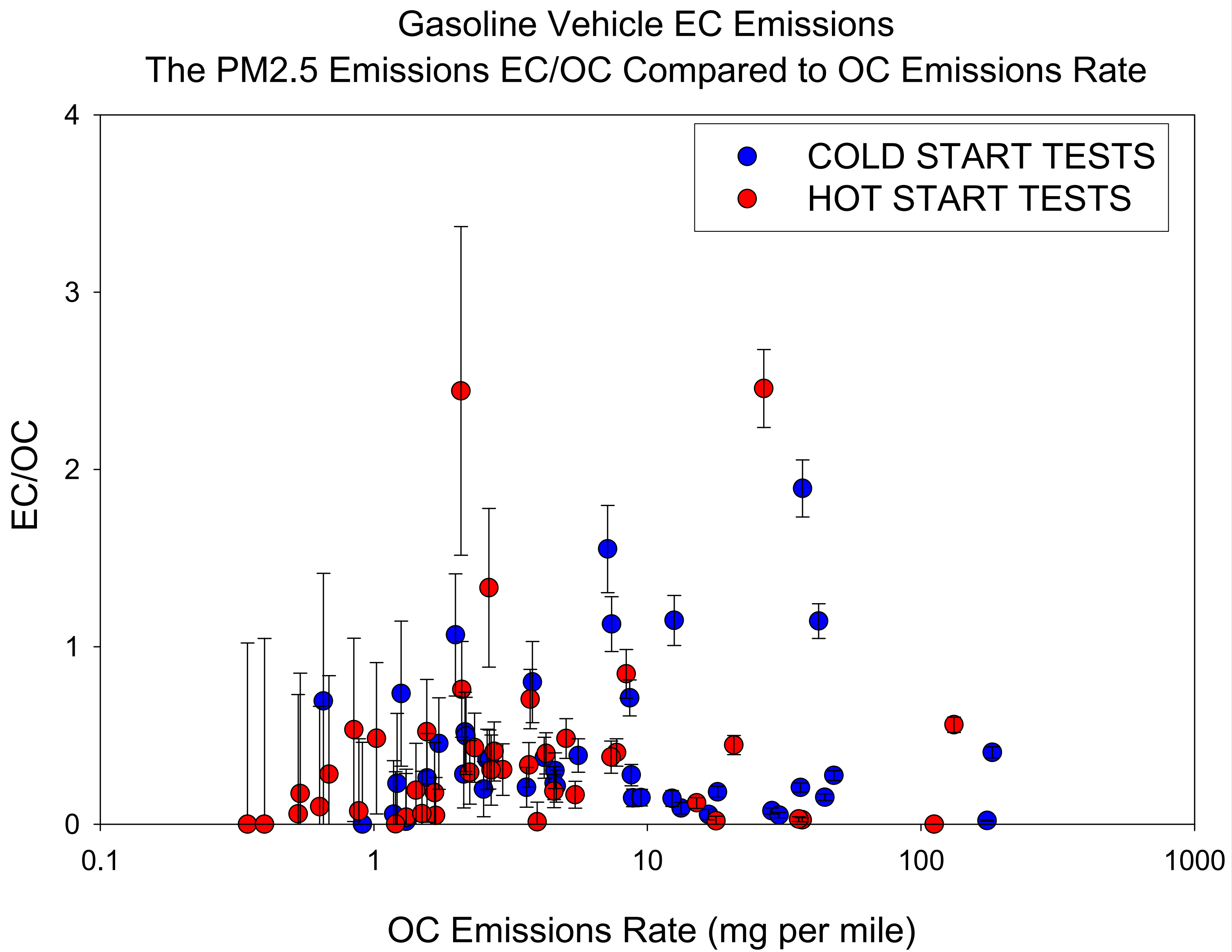


DOE Gasoline/Diesel Split Study

- Funding – James Eberhardt (DOE)
- Management/Recruitment – Doug Lawson (NREL)
- Gasoline Vehicle Testing – Peter Gabel (EPA)
- Diesel Engine Testing – Nigel Clark (WVU)
- Sampling, Chemical Analysis and Source Apportionment Modeling
  - Fujita, Zielinska, Arnott, and Campbell (DRI)
  - Schauer, Lough, and Christensen (UW-Madison)

Gas/Diesel Split Vehicle Test Matrix

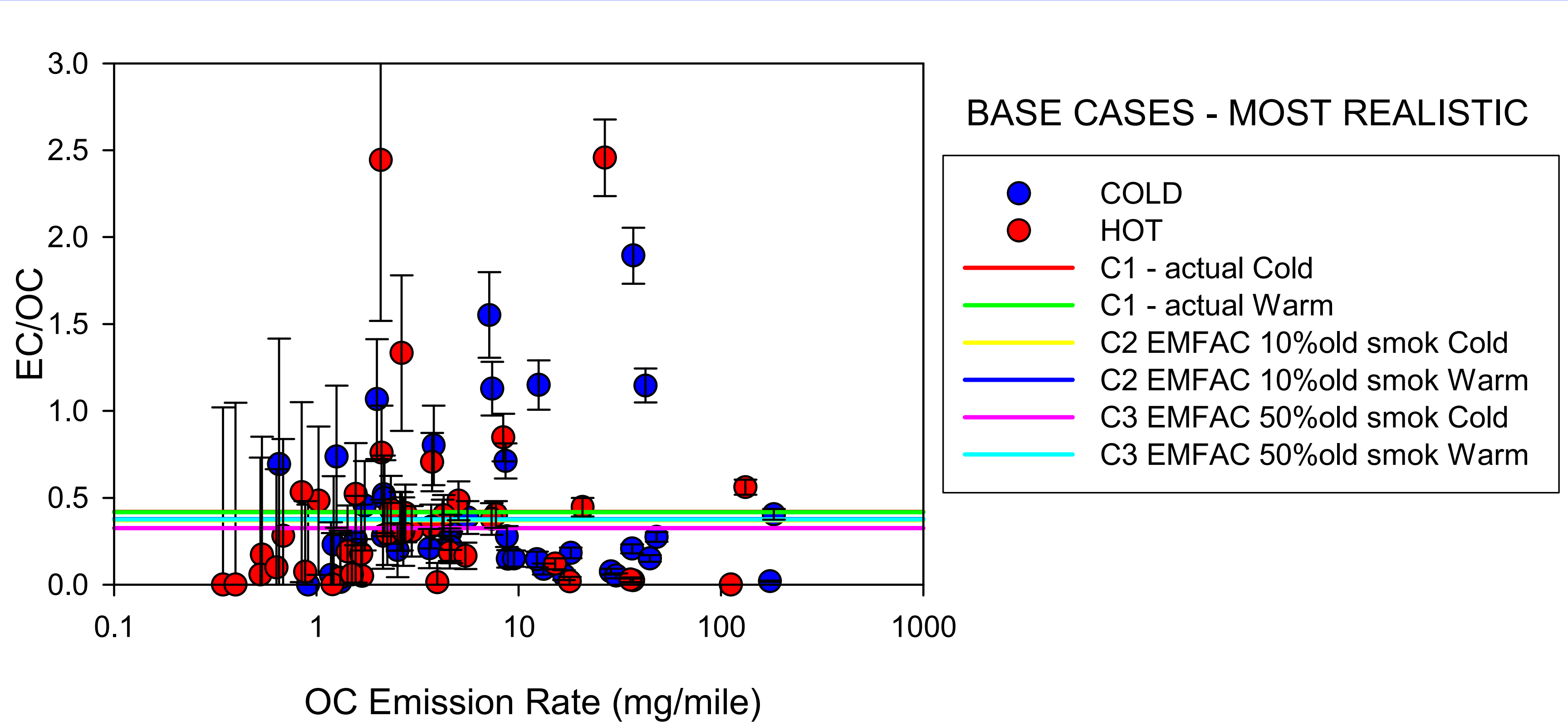
- Gasoline Powered Vehicles – 57 Vehicles
  - Cold UDC Test
  - Hot UDC Test
- Diesel Vehicles – 34 Vehicles
  - 34 CSHVR Cycles
  - 32 Highway Cycles
  - 34 Idle Tests
  - 10 Cold CSHVR Cycles
  - 2 Manhattan Bus Cycles
  - 10 Other Cycles
- Chemical Analysis
  - ECOC
  - Detail chemical speciation


Gasoline Vehicle EC Emissions
The PM2.5 Emissions EC/OC Compared to OC Emissions Rate
COLD START TESTS
HOT START TESTS
EC/OC
0
1
2
3
4
0.1
1
10
100
1000
OC Emissions Rate (mg per mile)

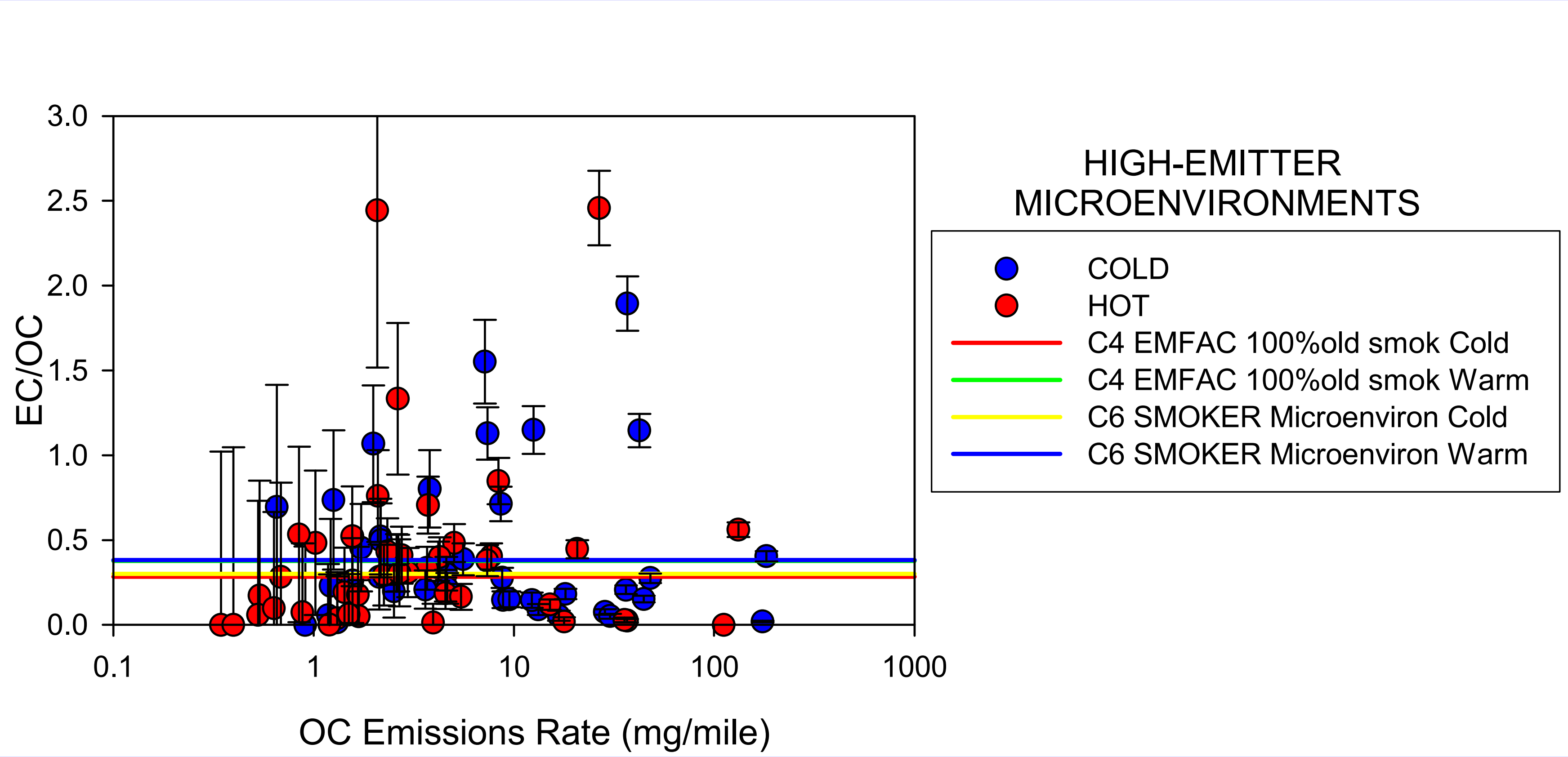
Key Observations – Gasoline Vehicles

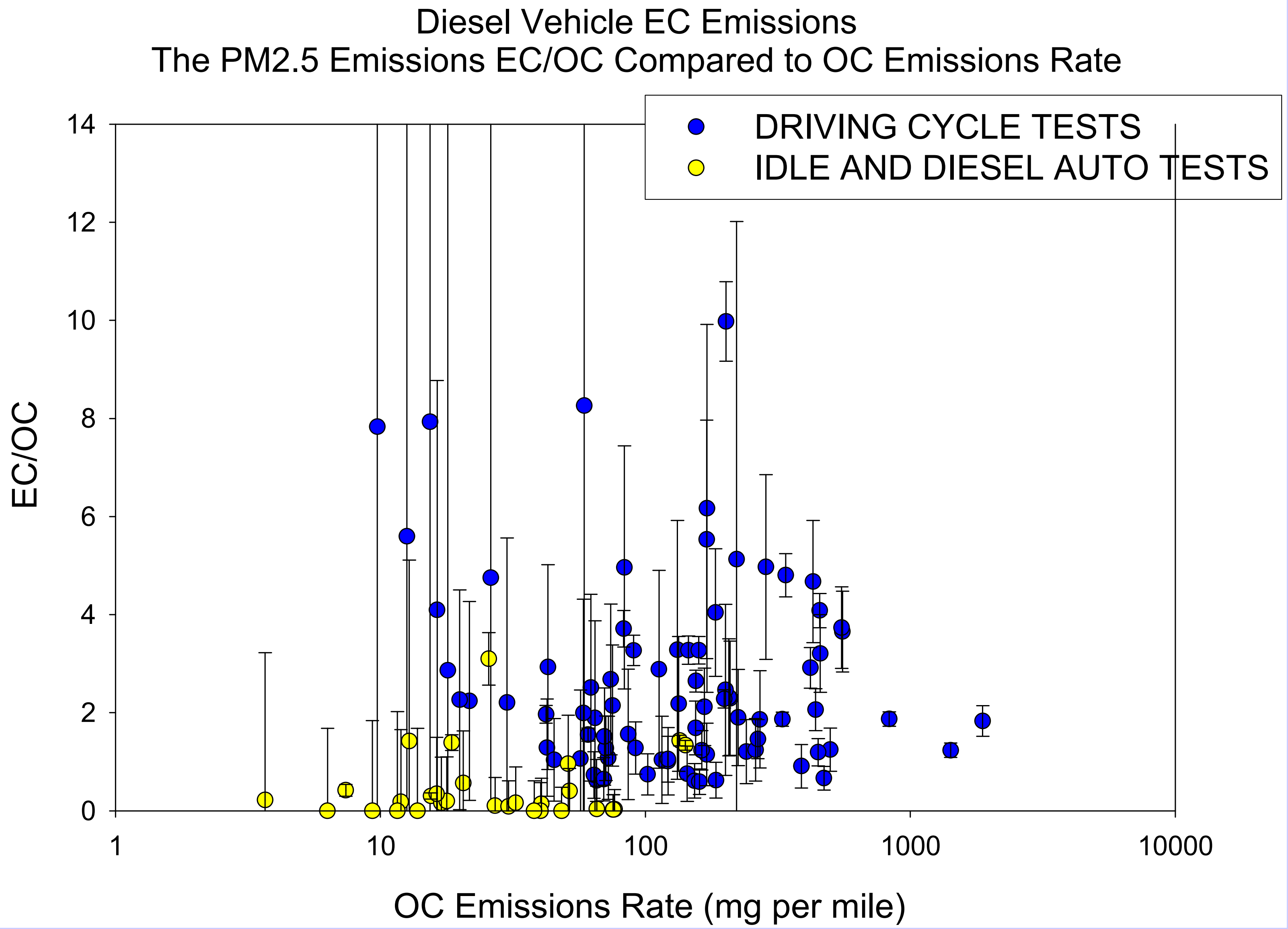
- Significant variability in EC emissions and the EC/OC ratio from vehicle to vehicle
- Generally higher EC emissions for Cold Start
- In the context of climate change and urban air pollution, we are not interested in variability of emissions from vehicle to vehicle
- We need to understand the variability in emissions from vehicle fleet to vehicle fleet
  - Vehicle distribution
  - Distribution of cold and hot start
- Sensitivity analysis was performed

Sensitivity of EC/OC to Gasoline Vehicle Distribution – Base Cases

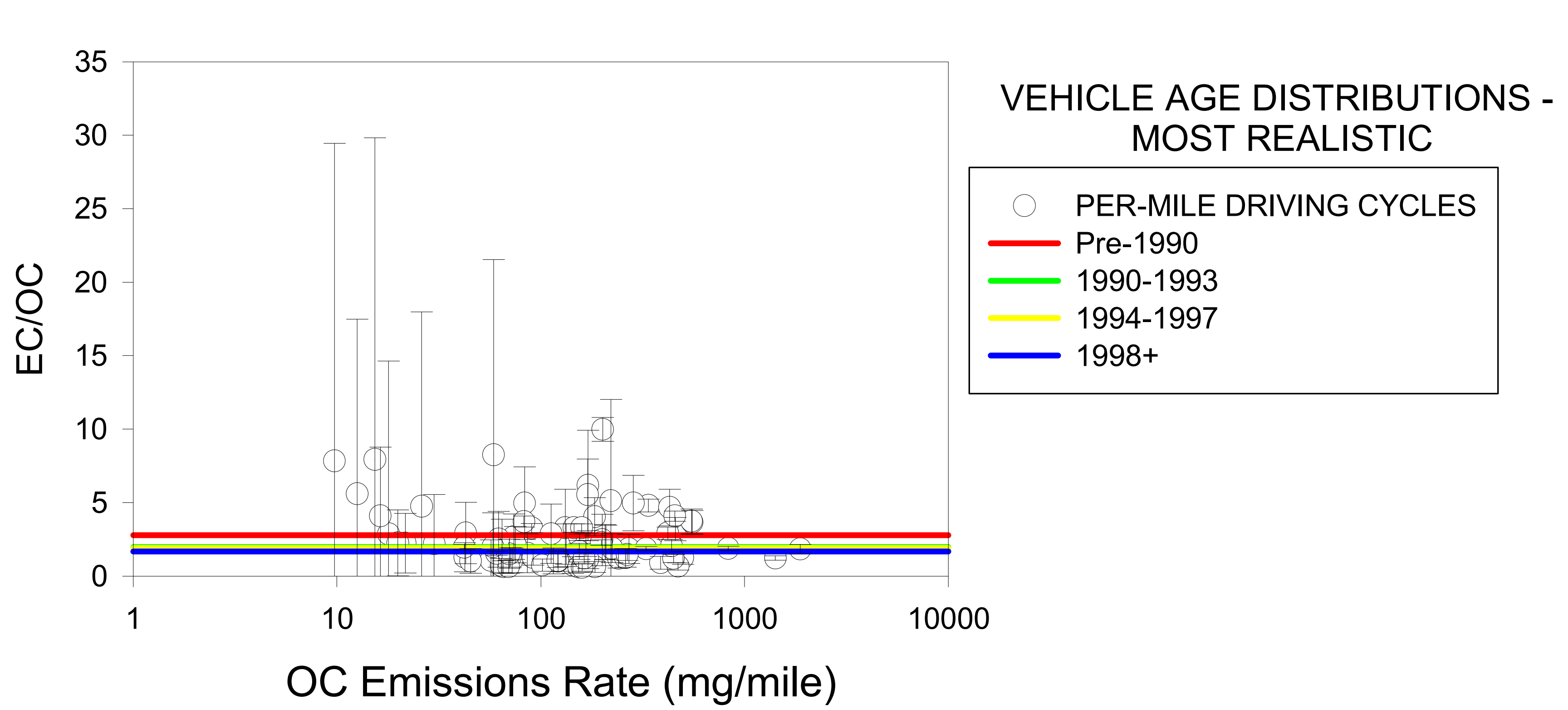


Sensitivity of EC/OC to Gasoline Vehicle Distribution – High Emitter Cases

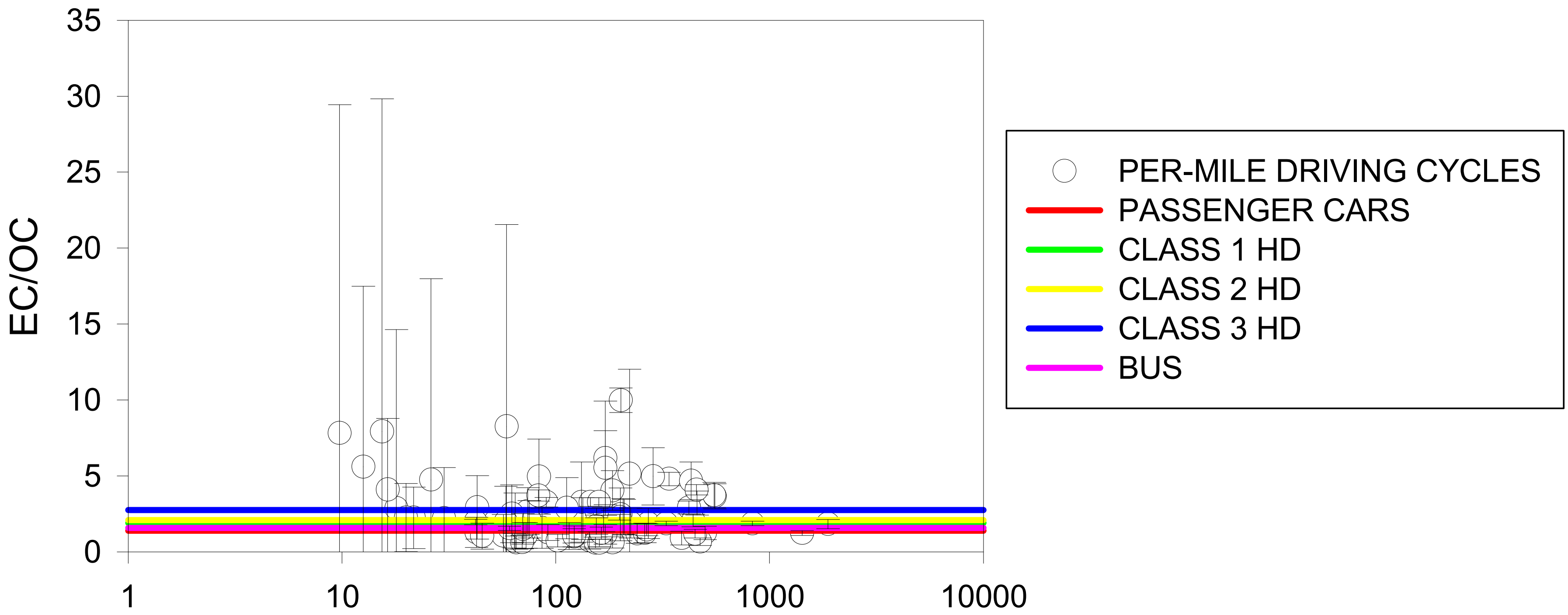



Diesel Vehicle EC Emissions
The PM2.5 Emissions EC/OC Compared to OC Emissions Rate
DRIVING CYCLE TESTS
IDLE AND DIESEL AUTO TESTS
EC/OC
0
2
4
6
8
10
12
14
1
10
100
1000
10000
OC Emissions Rate (mg per mile)

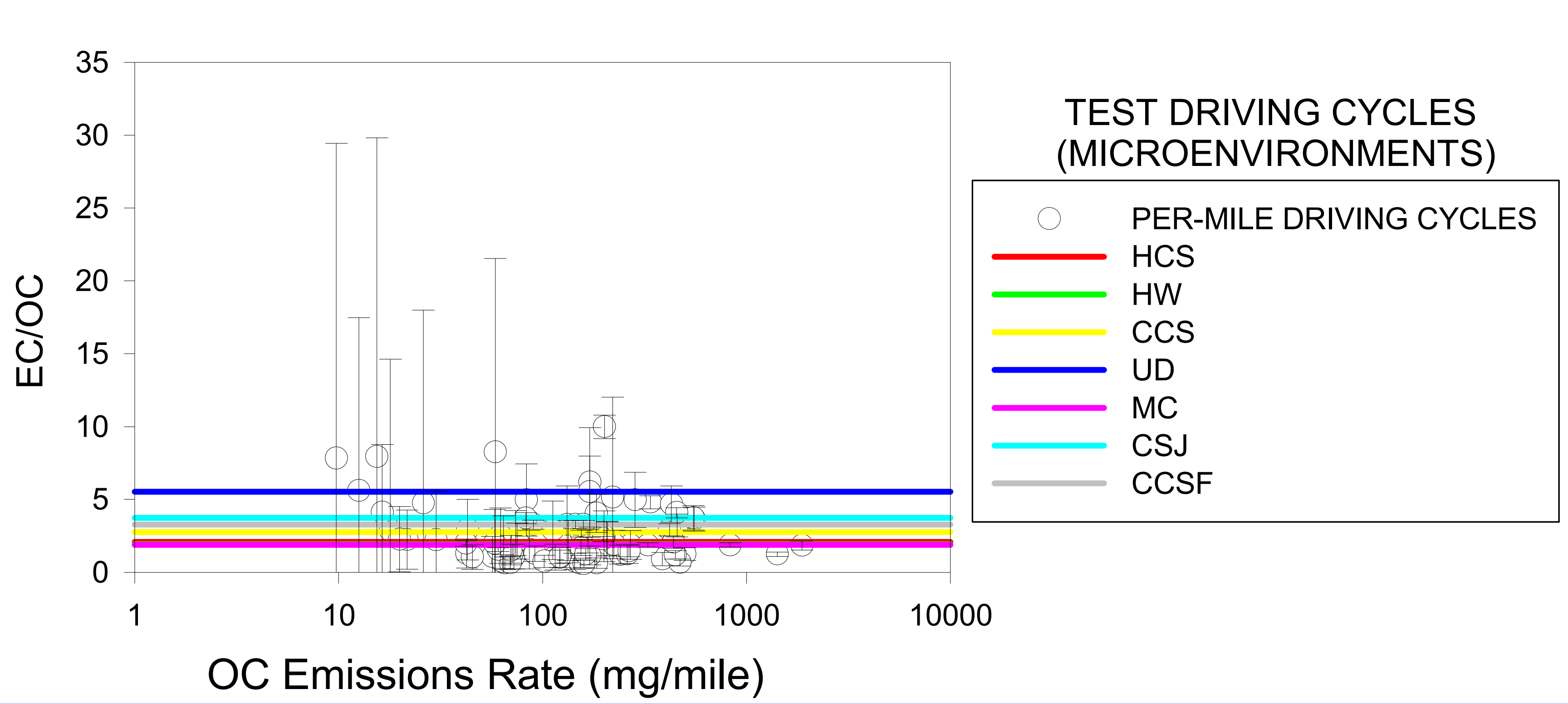
Sensitivity of EC/OC to Diesel Vehicle Age



Sensitivity of EC/OC to Diesel Weight Class



Sensitivity of EC/OC to Diesel Driving Cycle



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Ambient Monitoring Perspective

- Ambient monitoring can be a reality check for both top down and bottom up emissions inventory estimates for EC
  - Weekday-Weekend Variations
    - Example: Bae et al., 2004 - AWMA
  - Spatial Variations
  - Seasonal Variations
    - Example: Schauer et al., 2005 – HEI Final Report

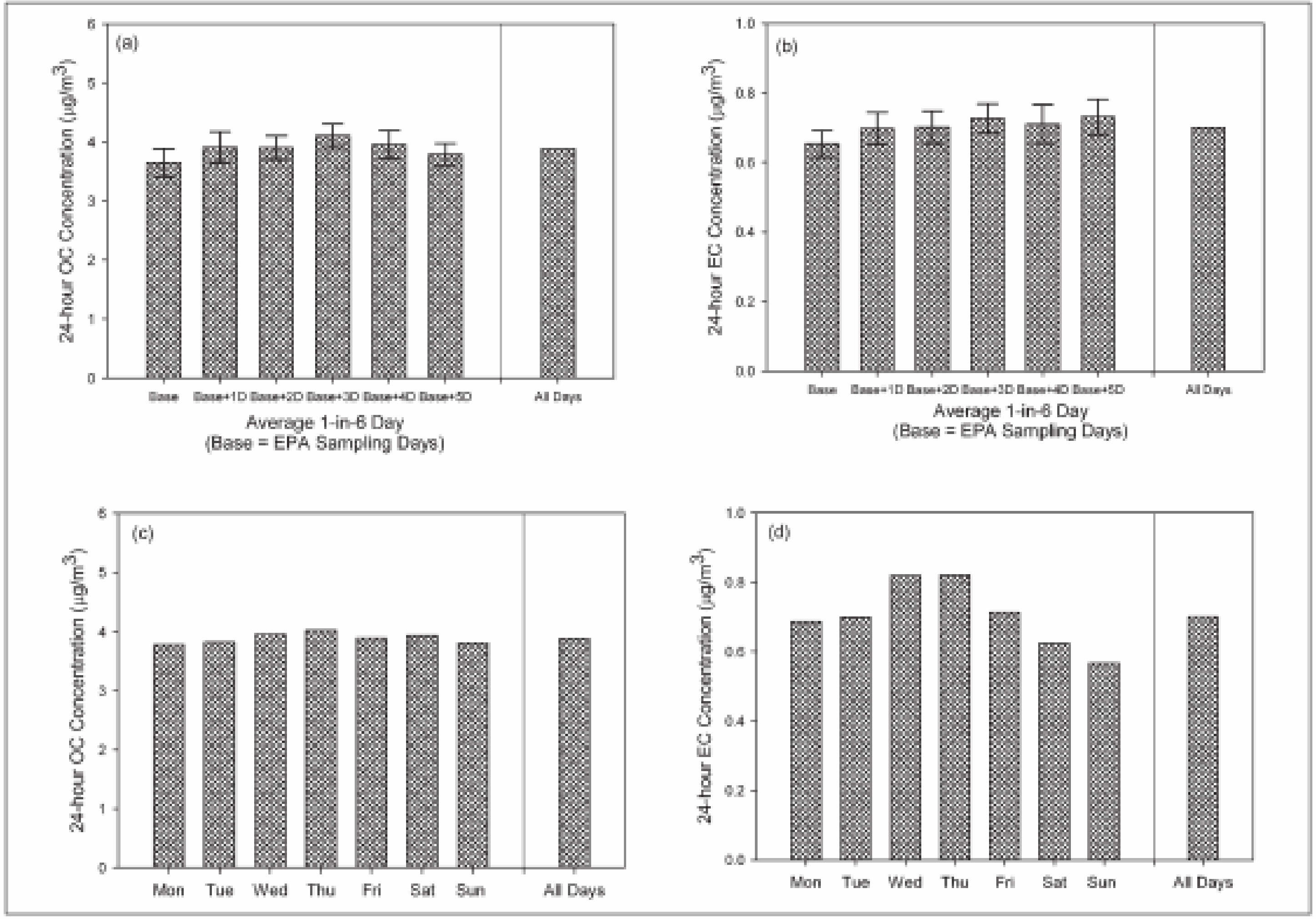
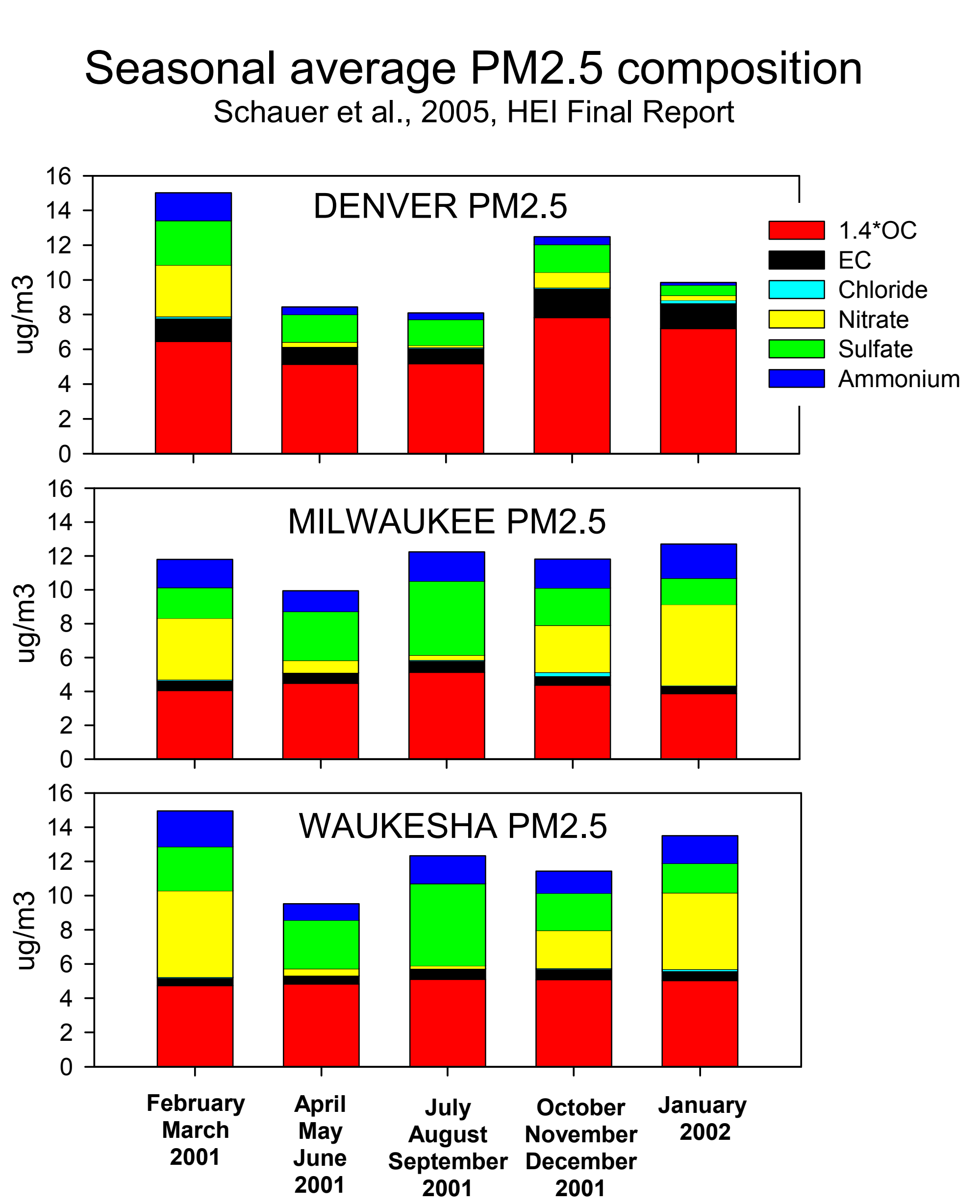


Figure 5. One-in-six and day-of-week average of daily measurement of denuded fine particle concentration at the St. Louis Midwest Supersite for the 2002 data set: (a) One-in-six OC; (b) One-in-six EC; (c) Day-of-week OC; and (d) Day-of-week EC.



Seasonal average PM2.5 composition
Schauer et al., 2005, HEI Final Report
DENVER PM2.5
MILWAUKEE PM2.5
WAUKESHA PM2.5
ug/m3
0
2
4
6
8
10
12
14
16
1.4*OC
EC
Chloride
Nitrate
Sulfate
Ammonium
February March 2001
April May June 2001
July August September 2001
October November December 2001
January 2002

Conclusions

- EC emissions for mobile sources are greatly impacted by vehicle fleet, driving cycle, fuel, cold start conditions, and engine technology and maintenance
- Need to focus on average fleet emissions and the sensitivity of emissions to vehicle fleet, driving cycle, cold start conditions and fuel.
- Need to use ambient measurement strategies as a reality check to bottom up and top down emissions inventory estimates
- Need to develop a parallel understanding of the EC emissions from other source categories